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California Polytechnic State University
San Luis Obispo, CA 93407

Development and Analysis of an Agility Assessment Module for Preliminary Fighter Design

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Technical Monitor
Andrew Hahn

Principal Investigator
Daniel Biezad

Graduate Assistant
Angelen Ngan

ABSTRACT

Development and Analysis of an Agility Assessment Module for Preliminary Fighter Design

By
Angelen Ngan

A study has been conducted to develop and to analyze a FORTRAN computer code for performing agility analysis on fighter aircraft configurations. This program is one of the modules of the NASA Ames ACSYNT (AirCraft SYNThesis) design code. The background of the agility research in the aircraft industry and a survey of a few agility metrics are discussed. The methodology, techniques, and models developed for the code are presented. The validity of the existing code was evaluated by comparing with existing flight test data. FORTRAN program was developed for a specific metric, PM (Pointing Margin), as part of the agility module. Example trade studies using the agility module along with ACSYNT were conducted using a McDonnell Douglas F/A-18 Hornet aircraft model. The sensitivity of thrust loading, wing loading, and thrust vectoring on agility criteria were investigated. The module can compare the agility potential between different configurations and has the capability to optimize agility performance in the preliminary design process. This research provides a new and useful design tool for analyzing fighter performance during air combat engagements in the preliminary design.

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1. INTRODUCTION

1.1 Agility Background

Agility and flight in expanded maneuvering envelopes have been considered as ways to improve aircraft combat effectiveness, which is a combination of survivability and mission effectiveness.[1] Traditional aircraft performance provides a good indication of maneuverability. The most maneuverable aircraft is the one that has the highest turn rate or can pull the most g's. The increasing maneuverability of current generation fighters has pushed maximum instantaneous g capability to the human limit. The measure of merit has to evolve from how many g's the aircraft can pull to how quickly it can achieve this limit. Agility is a measure of how quickly the aircraft can be maneuvered. It relates to minimizing the time required to perform some tasks or to achieve a desired aircraft state. The simplest definition of agility is the ability to move quickly in any direction or to perform a specific task. Future "superagile" vehicles will greatly expand the flight envelope with new longitudinal acceleration/deceleration capabilities, lateral and vertical direct force application, increased control authority in all axes, and increased sustained and instantaneous turning ability. The design which performed a set of maneuvers quickest would have the highest potential agility. Different sets of maneuvers will represent different versions of agility metrics. The need to define, measure, and quantify aircraft agility has been driven primarily by the inadequacy of traditional aircraft measures of merit and the emergence of advanced aircraft technologies and capabilities.[2]

Aircraft agility is a highly complex and integrated problem involving aerodynamics, propulsion, structures and controls. However, there are very few concrete definitions of what agility is. There are as many definitions of agility as there are researchers in this area. This has made it difficult to compare the results of one investigator with those of another.[3] As of today, the absolute definition of agility is still a subject of debate. Each of the definitions of agility proposed by the government and the industry represent different quantities measuring the performance capability of an aircraft.[4] The same aircraft could be less agile in one sense and more agile in another. The following are some of the proposed definitions by the government and industry in an effort to define and measure aircraft agility:

> Col. J.R. Boyd[5]: "Maneuver is the ability to change altitude, airspeed or direction in any combination. Agility is the ability to shift from one maneuver to another in minimum time. Agility is the ability to shift from one unfolding pattern or ideas and actions to another by being able to transition from one orientation to another."

> Pierre Sprey[5]: "Agility is directly proportional to the inverse of time to transition from one maneuver to another."

> Col. E. Riccioni[6]: "Agility is the ability to move from state space 1 (position, velocity, orientation) to state space 2 along an optimal path (i.e., minimum time or distance or radius)"

> Northrop[7]: "Agility is the ability to rapidly change both the magnitude and direction of the aircraft velocity vector."

> General Dynamics[8]: "Agility is the ability to point the aircraft quickly and get the first shot; continue maximum maneuvering for self-defense and multiple kills; and accelerate quickly to leave the flight at will."

> MBB[9]: "Agility is the time rate of change of the aircraft velocity vector."

> USAF Test Pilot School[10]: "Agility is the ability to shoot one's self in the 'derriere' instantly with perfect control." "Agility is that capability of an aircraft which allows the pilot to change the aircraft present state to a desired end state with quickness and precision."

> Eidetics[11]: "Agility is an attribute of a fighter aircraft that measures the ability of the entire weapon system to minimize the time delays between

determined by a combination of performance and handling quality characteristics of the aircraft, it is very difficult to completely define and apply agility through our present state of knowledge of either flying qualities and/or maneuvering performance.[13] Agility is a function of both maneuverability and controllability. The most maneuverable aircraft is the one that can go from the initial state to the desired final state most quickly. Agility of the aircraft does not have hard limiting values which means the more agility, the better. The indirect bounds on the achievable agility of an aircraft are maximum structural loads, stability and controllability limitations, and retaining the desired flying qualities characteristics.[12] The followings are some of the published agility metrics:

dynamic speed turn[8]: plot of P_s vs. turn rate.

pitch agility[11]: the time to pitch to maximum load factor plus time to pitch from maximum to zero load factor.

pitch agility criteria[11]: coefficient of pitching moment due to control surface deflection scaled with wing area, aerodynamic chord, and pitch axis inertia.

T_{90}[11]: the time to roll to and capture a 90° bank angle change.

torsional agility[11]: turn rate divided by T_{90}.

axial agility[11]: the difference between minimum and maximum Ps available at a given flight condition divided by the time to transition between the two level.

relative energy state[14]: ratio of aircraft velocity to corner speed after a 180° turn.

combat cycle time[14]: time to complete a maximum acceleration turn and regain lost energy.

pointing margin[14]: angle between the nose of an adversary and the line-of-sight when the friendly fighter is aligned with the line-of-sight.

roll reversal agility parameter[12]: product of time required to reverse a turn and the cross range displacement that occurs during the turn.

agility potential[15]: T/W divided by W/S.

Since the pilots, engineers and researchers now involved in agility have not as yet reached a commonly accepted definition of the term, it is not surprising that the proposed agility metrics deal with many different aspects of fighter capability. The various metrics proposed to measure agility deal in units of time, velocity, angular rate, distance and combinations of time, rate and distance.

1.2 ACSYNT Background

The ACSYNT (AirCraft SYNThesis) program for aircraft conceptual design was developed at NASA Ames Research Center during the 1970's to study the effects of advanced technology on aircraft synthesis. ACSYNT is a conceptual design code that is designed in a modular fashion, with each discipline of aircraft design analysis assigned to a different module or structured group of routines intended to handle that particular phase of analysis. Current ACSYNT analysis modules include Geometry, Trajectory (mission profile and performance), Aerodynamics, Propulsion, Stability and Control, Weights,

1.3 Objectives of the Research

The importance of agility is to provide a combat advantage over other aircraft. The goal for the agility study is to develop a methodology for inclusion of agility based requirements in aircraft conceptual design decisions. The design method is to provide quantitative estimates of aircraft agility characteristics and to be applied as a part of the optimization loop in future fighter aircraft design. The agility module in ACSYNT provides analysis of agility metrics and agility criteria. Implementation of technologies to improve aircraft agility are analyzed and optimized in ACSYNT while their penalty and impact on other design constraints are determined. This analysis provides some insight into the utility of agility technologies and the combat effectiveness of an aircraft configuration.

2. AGILITY METRICS

The general character of the agility module is to operate on the upper boundary of what is frequently referred to as the doghouse plot. This is a graph of turn rate versus Mach number at a specified altitude. Figure 1 illustrates a typical doghouse plot.

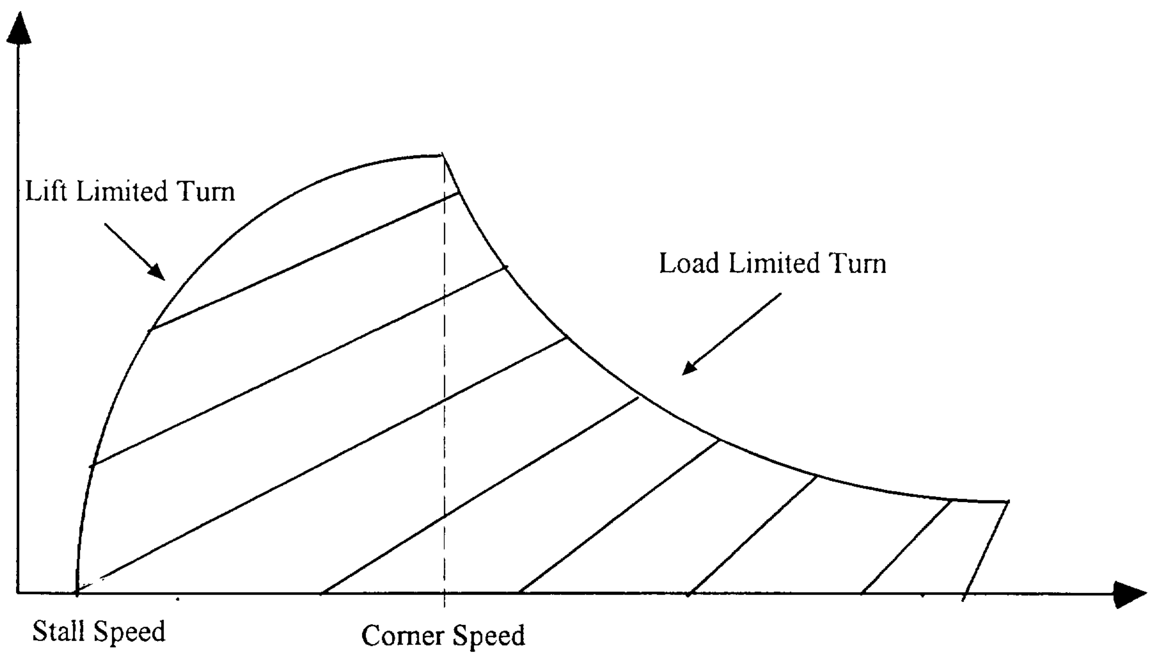
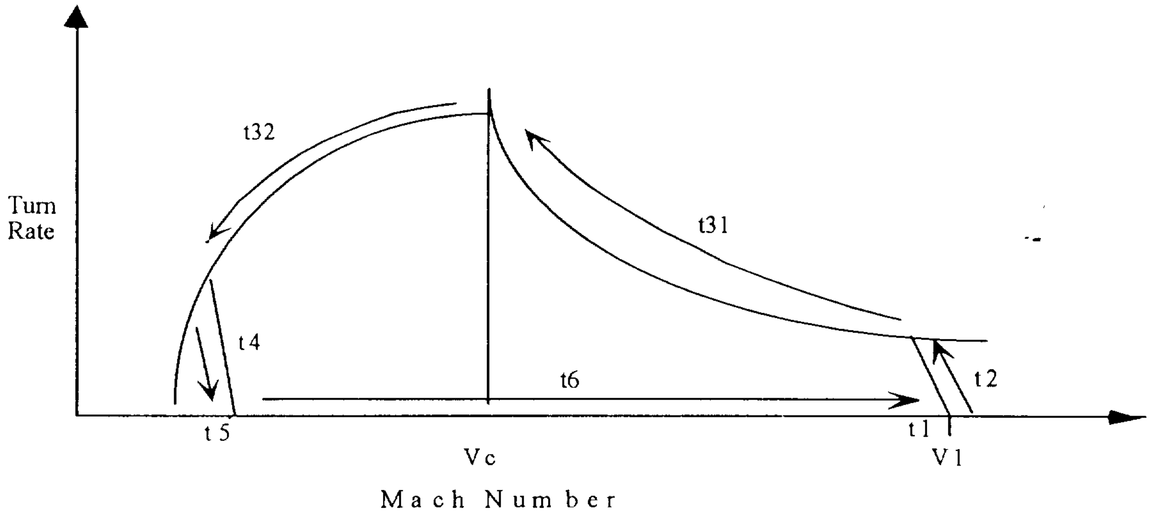


Figure 1 Illustration of the Doghouse Plot

The peak in the upper boundary represents the highest turn rate for any Mach number. The Mach number corresponding to the peak is usually called corner speed. The aircraft's turn rate is limited by different constraints depending on which side of corner speed it is flying. Above corner speed, the aircraft can aerodynamically generate a higher load factor than the aircraft's structure can withstand. The aircraft is said to be "load limited" with the maximum turn rate determined by the maximum designed load factor. Below corner speed, the aircraft is operating at its maximum lift coefficient and cannot aerodynamically generate the design load factor. This region is said to be "lift limited." The definition of corner speed can be said as the Mach number that produces the maximum design load factor at maximum lift coefficient. In a dogfight, pilots try to get to corner speed as quickly as possible as it provides the best turn rate. Two specific metrics are discussed because they are being developed as part of the ACSYNT agility module. The metrics discussed illustrate the differences of opinion on what agility is. Some analyze how efficiently aircraft use energy to achieve an objective and how quickly they can regain lost energy. Other metrics analyze the quick-action nose pointing capability of a configuration. The agility module developed is adaptable enough to accommodate several philosophies and their respective metrics.

2.1 Combat Cycle Time (CCT)

The combat cycle time metric measures the time it takes to turn through a specified heading change and then accelerate to regain the energy lost during the turn. The exact maneuver is as follows: roll into turn, pitch to specified load factor, hold turn through specified heading change, pitch back down to unity load factor, roll to wings level and accelerate back to original speed. The objective is to complete this maneuver in the least amount of time. In this maneuver the aircraft operates along the upper boundary of the doghouse plot. Figure 2 illustrates the path the aircraft follows on this plot over the course of the maneuver.



Legend:

V1-starting and ending speed

t1-time to bank into turn

t2-pitch up to load factor

t31-time spent in load limited turn

t32- time spent in lift limited turn

Vc-corner speed

t4-pitch down to unity load factor

t5-roll to wings level

t6-time to accelerate back to V1

Figure 2 Combat Cycle Time Maneuver Circuit

2.2 Pointing Margin (PM)

Aircraft nose pointing at the adversary in shorter time will be one of the primary capabilities required in the design of future agile fighters. Pointing the nose/weapon of the aircraft at the adversary first will be required to win, since pointing first means having the opportunity to shoot first.[14] The pointing margin metric measures how fast an aircraft can point his nose at an adversary aircraft. This parameter is a function of flight condition, mach number, altitude, and heading angle of the turn. The maneuver is shown in Figure 3. The two aircraft begin at the same Mach number and nearly the same location in space but pointed in opposite directions. At the start of the metric both aircraft begin a maximum acceleration turn toward one another. The aircraft that first brings his line of sight upon the opposing aircraft's position is considered the most agile. Pointing margin for the friendly fighter is the angle between the nose of the adversary aircraft and the line of sight joining the two fighters at the instant the friendly fighter first points its nose/weapon at the adversary's aircraft. The greater this angle the longer it takes the losing aircraft to acquire the winning aircraft's position. This provides the winning aircraft a longer missile flight time and a better chance of a kill. A first-shot capability is considered a vital edge in winning aerial combat.

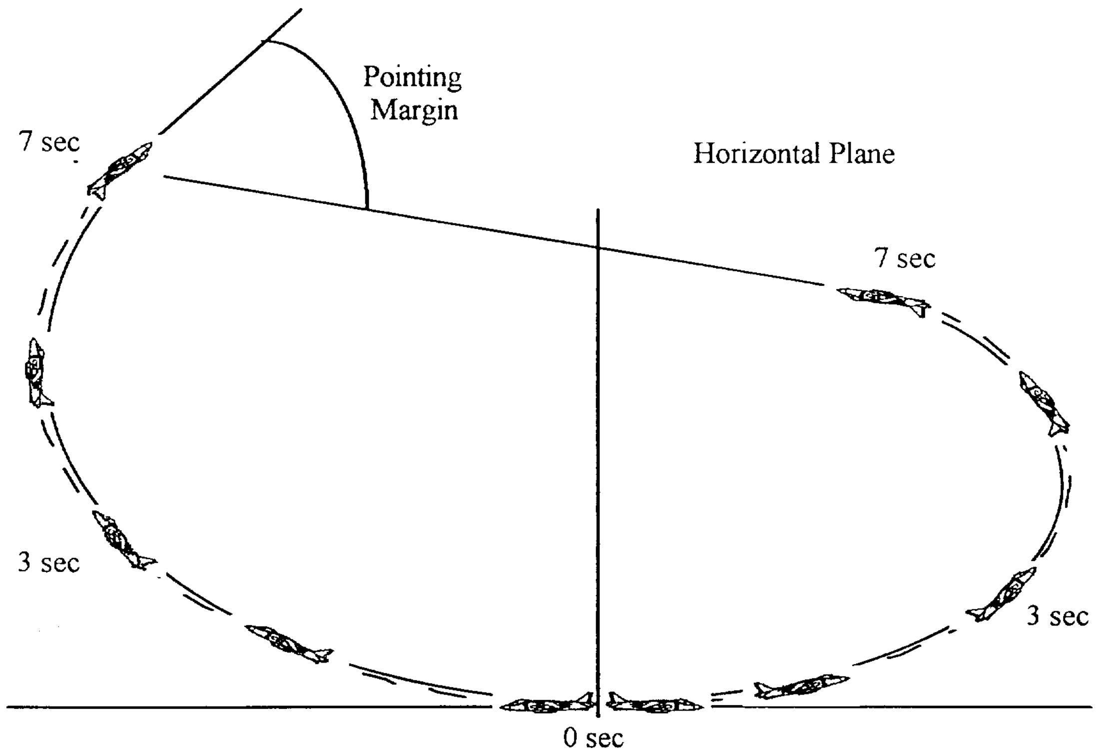


Figure 3 Pointing Margin Agility Metric

3. METHOD

This research consists of two parts, a validation phase and a methodology enhancement phase. Validation consists of evaluating a present inventory fighter against existing maneuver data. Methodology enhancement will involve identifying new, unsupported agility metrics and adding them to the existing code framework. A currently unsupported agility metric, Pointing Margin, has been written and added to the existing code framework. The improvements made to the aerodynamics, propulsion, and mass properties modules of ACSYNT were incorporated into the existing agility metric analysis. An effort was made to enhance the existing module by implementing stability and control power derivatives which would modify the governing equations. Digital Datcom can be used currently to obtain stability and control derivatives at different angle of attacks and altitudes. However, the Digital Datcom program is not linked with ACSYNT and it has to be run stand alone. Therefore, the information obtained from this program has to be input by hand to the agility module. Development and implementation of this module would allow the user to time step through a sequence of maneuvers to evaluate the time and positional performance of a given aircraft configuration.

3.1 General Methodology

The overall structure of the code is a time-stepping routine that tracks pertinent parameters over the course of the agility maneuver. This is basically a simulation technique. Since CCT and PM were selected as archetypes for the simulation package, there exists separate subroutines dedicated to analyzing those metrics. There are two options to evaluate the other agility metrics. The user may input the desired maneuver

3.2 Flight Dynamics

The agility metric maneuvers were divided into separate segments. Figure 4 illustrates the four types of maneuver segments: rolls, pitches, turns, and accelerations. Segments are further divided into functional and transient categories.

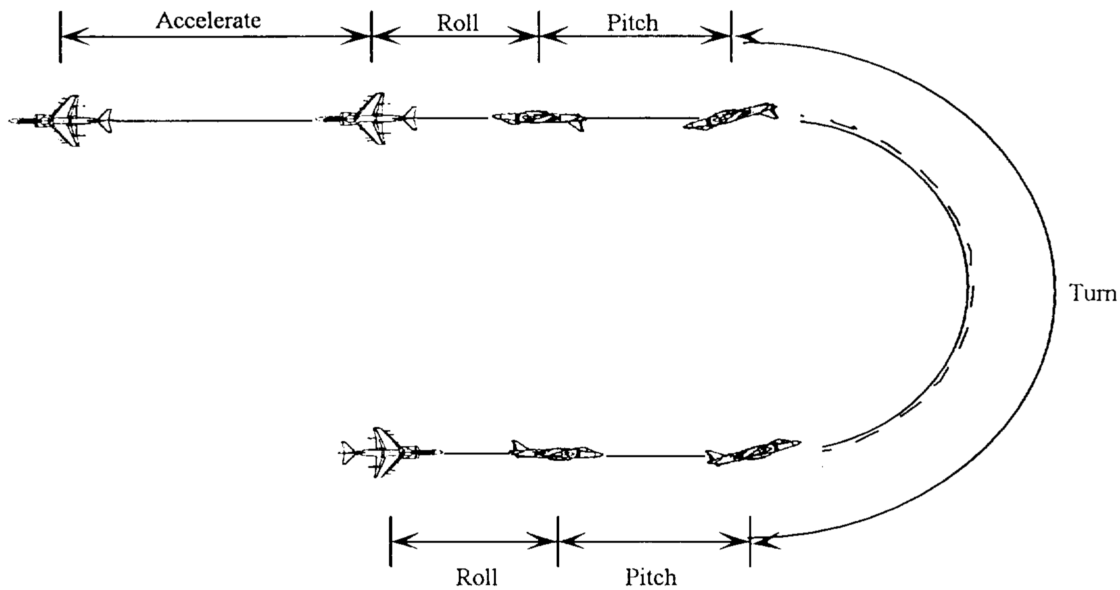


Figure 4 Breakup of Metric Maneuvers into Maneuver Segments

Turns and accelerations actually represent quasi-steady turns and straight line accelerations. The term "quasi-steady turn" refers to a steady, level turn maneuver where the velocity may be changing. If a turn cannot be sustained, the aircraft loses air-speed. In order to maintain the load factor, the angle of attack must gradually increase. If the aircraft is lift-limited and cannot sustain the load factor, the bank angle must gradually decrease to maintain the level turn. These changes in angle of attack and bank angle occur slowly so that the steady turn equations of motion can be used and the perturbation equations need not be employed. It is this type of turning maneuver that is termed quasi-steady.

Agility metrics are categorized by time scales (transient, functional) or by the type of motion involved (lateral, pitch, axial). Functional maneuver segments deal with longterm changes (>5 seconds) in aircraft energy state, position and attitude. They quantify how well the fighter executes rapid changes in heading or rotations of the velocity vector. Emphasis is on energy lost during turns through large heading angles and the time required to recover kinetic energy after unloading to zero load factor. Equations of motion for the functional segments were steady-state equations for turns and rectilinear flight. Transient maneuver segments deal with short-term changes (1-5 seconds) in aircraft accelerations, positions and orientation. They quantify the fighter's ability to generate controlled angular motion and to transition quickly between minimum and maximum levels of specific excess power. Equations of motion for the transient segments were standard longitudinal and lateral-directional perturbation equations.

Note that the present module is best suited for functional type metrics because ACSYNT's stability module is not fully operational and the flight control module is not yet incorporated. Once those modules are fully operating, the transient maneuver analysis capabilities will be improved. Currently, the transient metrics may be analyzed, but the analytical models are not as robust as for the functional type segments.

The turn subroutine is designated as quasi-steady since the turns are not assumed single degree of freedom, lateral equation of motion. It uses aileron effectiveness and roll damping to construct a single degree of freedom roll schedule.

3.3 Code Options and Features

The agility operating code contains some options and features for the users to customize the maneuvers by manipulating the input parameters. These features include the angle of attack limiter, throttle control and turning speed capture, thrust vectoring, air brake, and external stores release and weight/moment of inertia control.

4. CODE VERIFICATION

Code verification consisted of three phases. A brief review is mentioned for the first two phases that were completed in a previous research. The complete results can be found in Reference 16.

The first phase was to test code logic and to ensure continuous, believable time histories of the tracked variables. All the code features and options were tested thoroughly as well.

The second phase was to compare the agility module's maneuver analysis with the combat analysis in ACSYNT's trajectory module. This phase would ensure that the agility module was retrieving aerodynamic and propulsive data properly and that the physical equations used for maneuverability are consistent with an independent performance package NASA has used for years. The agility module's sustained and instantaneous turn rates, radii, excess powers, angles of attack and lift and drag coefficients were compared with those of the trajectory module over a range of Mach numbers. This validation phase indicated that the agility module performs time dependent maneuverability analysis properly and the time-stepping simulation technique is effective in tracking an aircraft's performance throughout a maneuver.

For a more valid comparison, the agility module should be checked against flight test data. Therefore, the last and most important phase of validation was to compare agility analysis with the existing maneuver data of an inventory fighter. The only flight test maneuver data available was from one of the NASA Dryden Flight Research Facility's F/A-18 HARV flight tests. The flight test data contained a very comprehensive list of parameters except for the positional tracking, namely, XYZ positions. The positional comparison could not be completed in light of the lack of data. The parameters being compared are time, mach number, heading angle, roll rate, bank angle, load factor, angle of attack, and turn rate. The technique that is used for the validation is called simulation matching in which the real data is being tested in the code to see if it produces similar result.

A test was performed to ensure the code was working properly for the individual segments, such as roll, pitch, etc. This was done by testing piecewise segments. The piecewise test proved that the code provides acceptable result for each individual segment. Theoretically speaking, a complete maneuver should be performed the same way as when different segments are added together, if each piece is performed as expected. The flight

[redacted]

controlling these boundary conditions was critical, since the original code initialized those parameters to be zeros, changes had to be made in the appropriate subroutine. Other than these necessary inputs, the code was not changed in anyway.

While results were very good, there are several factors that introduce errors in this [illegible]

validation. Any difference between the simulated maneuver and the actual maneuver is going to cause the error in the analysis. One source of error is a discontinuity between segment boundary conditions. Figure 5 shows mach number vs. time for a typical maneuver. As seen on this graph, the matching is quite good. The average percentage error between the actual and the ACSYNT curve is 0.21%. The discontinuities in the graph can be seen more clearly in Figure 6. This figure shows actual, ACSYNT, and ACSYNT-Modified curves. The discontinuity is located at the transition from one segment to another. The ACSYNT-Modified curve is generated by assuming that the curve is continuous instead of discrete. It shows how the curve should be without the discontinuity between each segment. The difference between the ACSYNT and the ACSYNT-Modified results due to the fact that the boundary conditions between segments are not forced to be the same in the code. If the boundary conditions of the beginning of a segment are the same as the end of the previous segment, then a piecewise continuous analysis can be obtained easily. When there is only one boundary condition, the analysis is continuous by definition. Another source of error has to do with simulation vs. reality. As shown in Figure 7, the curves clearly distinguish the behavior of a real and a simulated maneuvers. For a real maneuver, the flight is very smooth with a gradual increase in the load factor. Conversely, the simulated flight jumps to the designated g's for each segment. This would certainly contribute errors into the validation. Comparisons between heading percentage error is acceptable for this kind of analysis. Thus it can be concluded that this validation analysis is satisfactory and the existing computer code is valid.

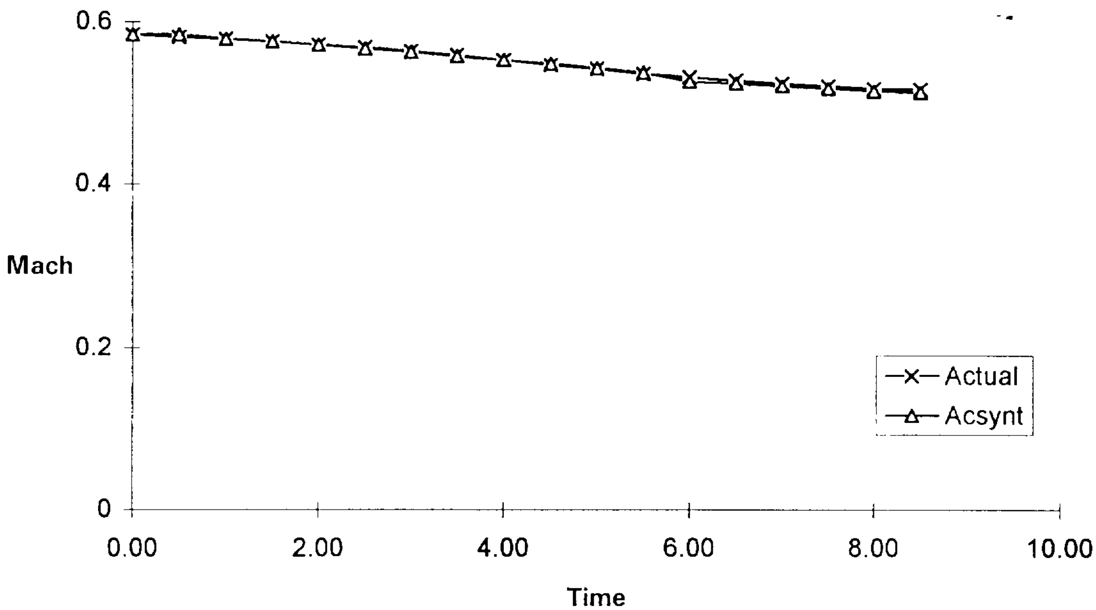


Figure 5 Comparison of Simulated and Actual Maneuvers - Mach vs. Time

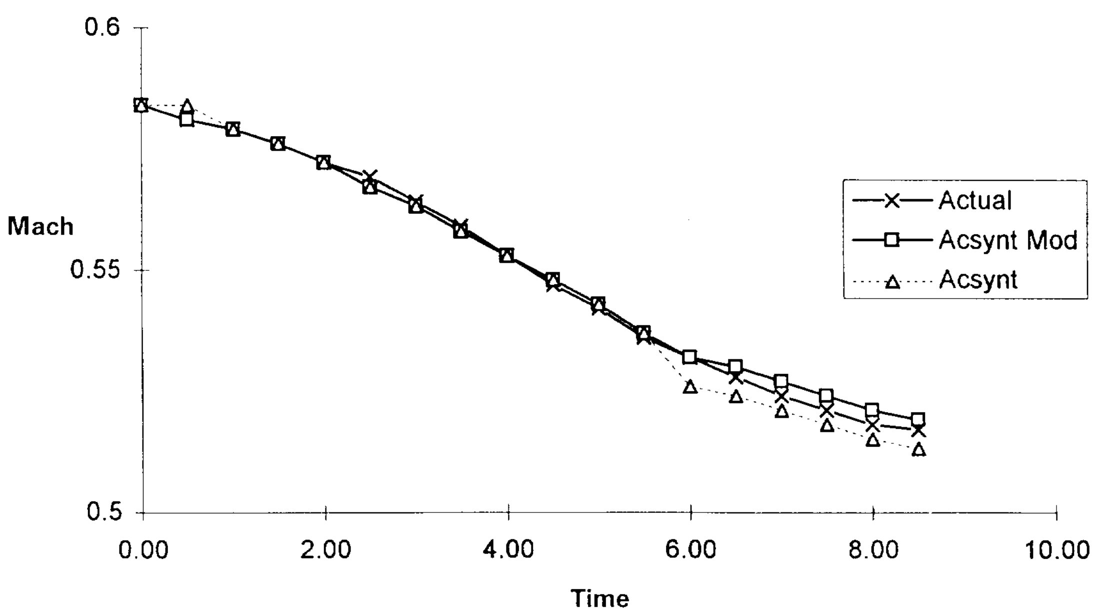


Figure 6 Comparison of Simulated and Actual Maneuvers with Modification - Mach vs. Time

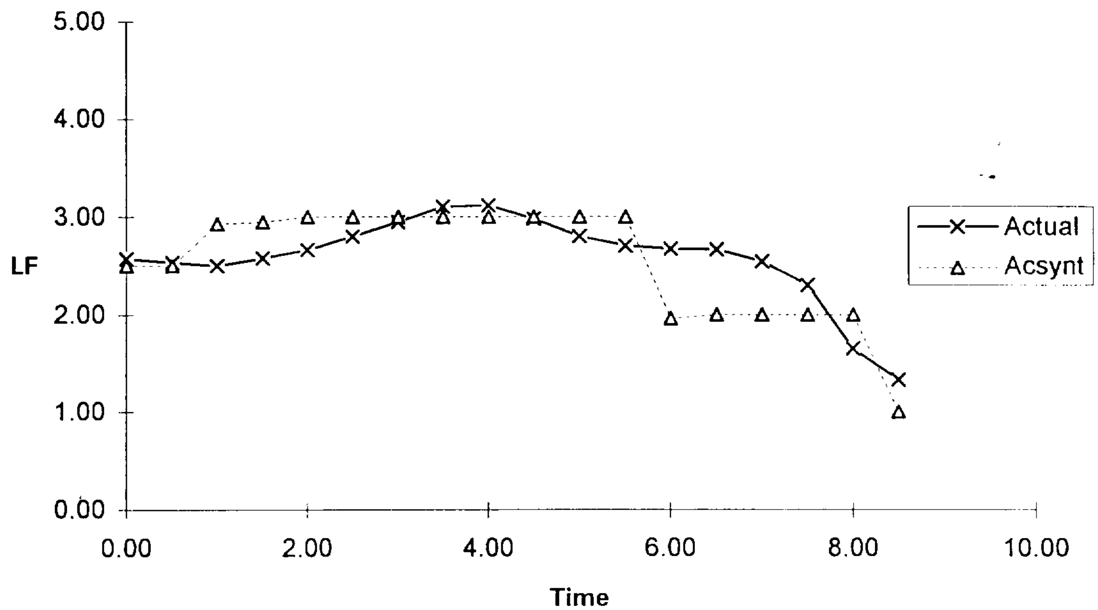


Figure 7 Comparison of Simulated and Actual Maneuvers - Load Factor vs. Time

	% error
Mach Number	0.21%
Heading Angle	0.58%
Bank Angle	20.70%
Load Factor	9.80%
Turn Rate	13.83%
Angle of Attack	17.44%

Table 1 Percentage Error Between Simulated and Actual Maneuvers for the Agility Code Validation

5. TRADE STUDIES

5.1 Effect of Thrust Loading and Wing Loading

Thrust Loading (T/W) and Wing Loading (W/S) are the two most important parameters affecting aircraft performance. An aircraft with a higher T/W will accelerate more quickly, climb more rapidly, reach a higher maximum speed, and sustain higher turn rates. However, the larger engines will consume more fuel throughout the mission, which

will drive up the aircraft's takeoff gross weight to perform the design mission. W/S affects stall speed, climb rate, takeoff and landing distances, and turn performance. Wing loading determines the design lift coefficient, and impacts drag through its effect upon wetted area and wing span. Wing loading has a strong effect upon sized aircraft takeoff gross weight. If the wing loading is reduced, the wing is larger. This may improve performance, but the additional drag and empty weight due to the larger wing will increase takeoff gross weight (roll-pitch-turn) maneuver was performed for the test runs. The effects on T/W and W/S on PM are discussed.

5.1.1 Effect of Thrust Loading on Pointing Margin

The baseline fighter along with four other configurations were flown through the same maneuver. These configurations were altered only in the available level of thrust specified as a percentage of the baseline configuration's available thrust (80%, 90%, 110%, 120%).

Figure 8 illustrates the time differences for each segment of the pointing margin maneuver for all five configurations. The maneuver times steadily increased with increased available thrust and the lowest thrust aircraft performed the maneuver in the least amount of time which also implies that the lower thrust aircraft completed the turn segment slightly quicker than the higher thrust aircraft.

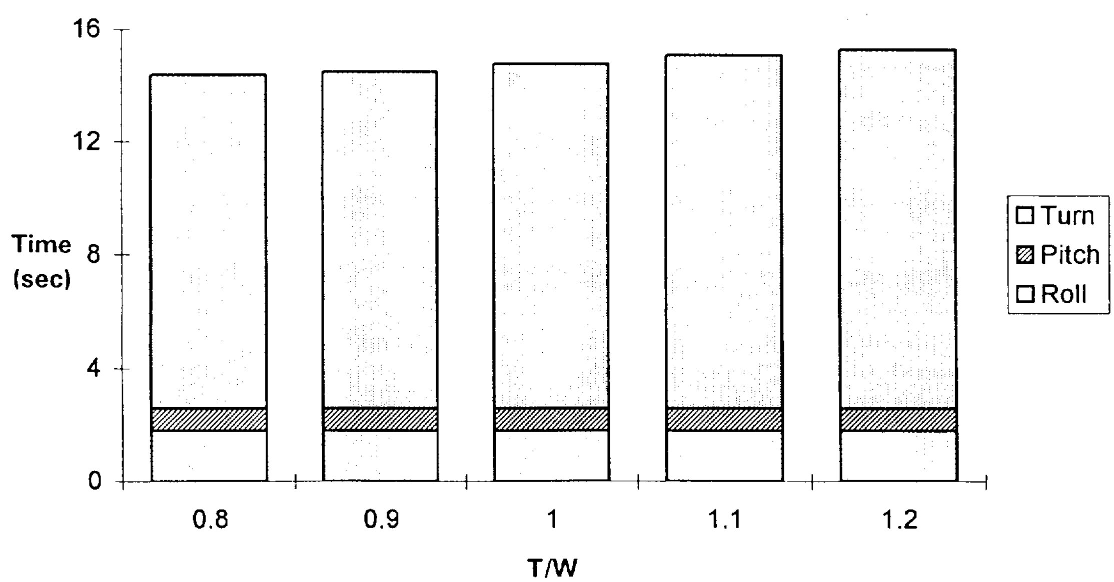
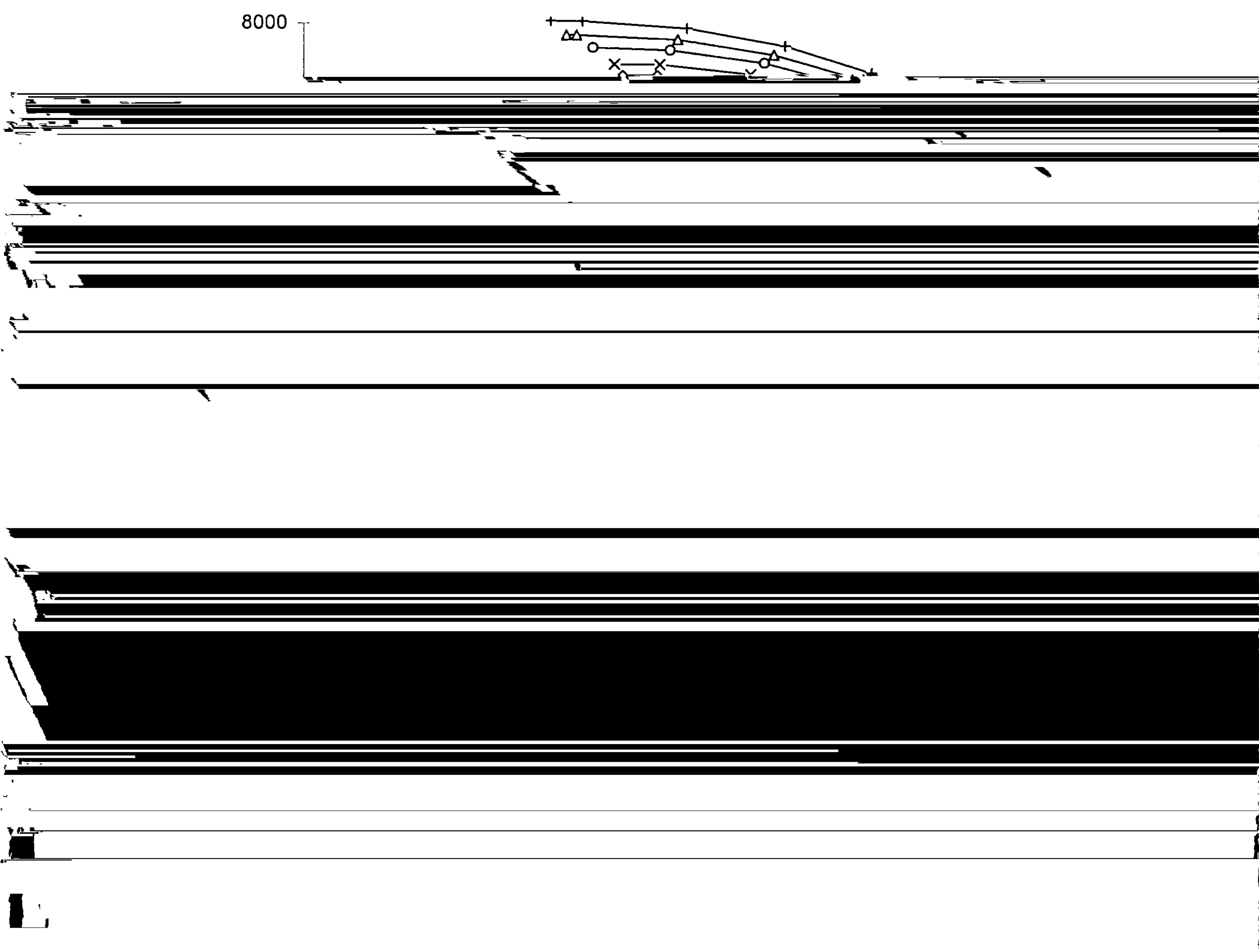


Figure 8 Pointing Margin Total Maneuver Time for Different Thrust Loadings

Turning speed determines an aircraft's highest turn rate. It is understandable why the lower thrust aircraft completed their turns sooner. Their higher decelerations placed them in speed regimes with higher turn rate than the greater thrust aircraft and thus were able to achieve superior turns. If the starting velocity were below the turning speed, the higher thrust aircraft would be better able to accelerate to and maintain the turning speed. It is situations like this that make the development of agility criteria so difficult. The configuration can be entirely dependent on the specific situation. Figure 9 illustrates the turn profile in the horizontal plane of the maneuver. The lower thrust configurations turn tighter and possess a positional advantage over the course of the turn segment.



that was discussed. The aircraft that reaches the turning speed and completes the turn sooner can always obtain a better positional advantage.

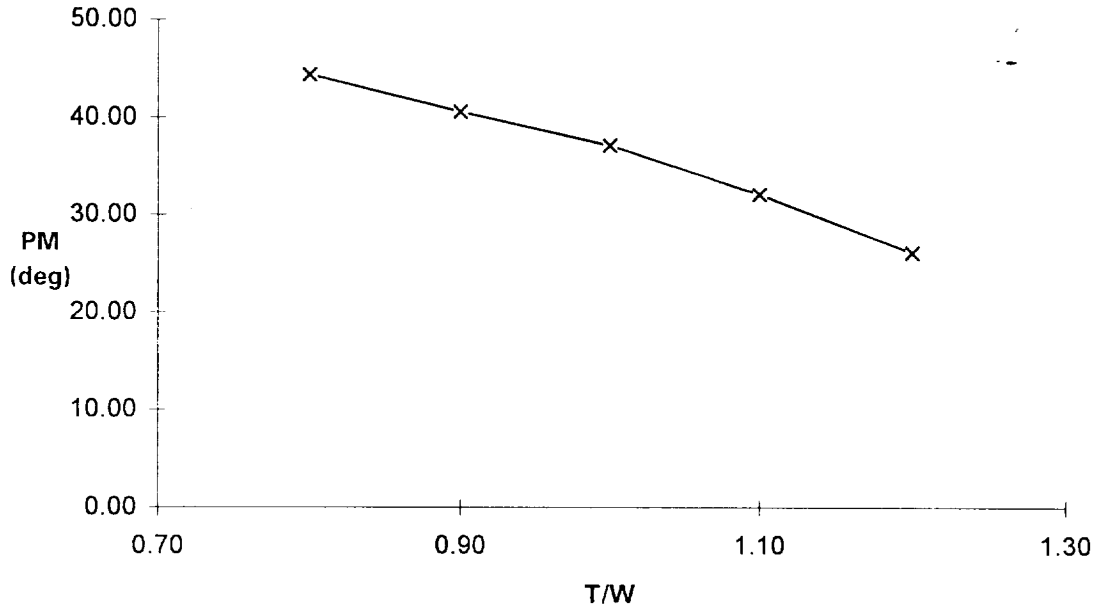


Figure 10 Pointing Margin vs. Thrust Loading

The impact of thrust loading is entirely dependent on what is considered most important. For PM type of maneuver, a lower thrust aircraft would be a better choice because lower thrust configurations possessed a positional advantage up to the end of the turn segment. The conclusion of this study is there is a tradeoff of what type of performance is most crucial and what are its costs.

5.1.2 Effect of Wing Loading on Pointing Margin

The baseline fighter along with four other configurations were flown through the same maneuver. These configurations were altered only in the wing loading and all other input parameters were held constant. The selected wing loadings were 65, 70, 85, and 90 psf with a baseline wing loading of 78.4 psf.

Figure 11 illustrates the time differences for each segment of the pointing margin maneuver for all five configurations. The total time to complete the maneuver was very similar for all configurations, but there was a difference in the times for each maneuver segment. The higher loaded aircraft completed the turn segment slightly faster than the less loaded configurations. This is because a higher loaded aircraft produces higher lift coefficients, thus increases induced drag and results in greater deceleration and velocity deficit. Similar to the thrust loading results, the quicker approach to turning speed provided higher turn rates and resulted in a shorter time for a turn. Figure 12 plots the turn profile in the horizontal plane of the maneuver. This graph shows the higher loaded aircraft has a turn advantage both in time and in space. The points discussed above are also well illustrated in Figure 13. It shows that a better pointing position can be obtained with a higher wing loading which correspond to the fact that a higher wing loading has a turn advantage.

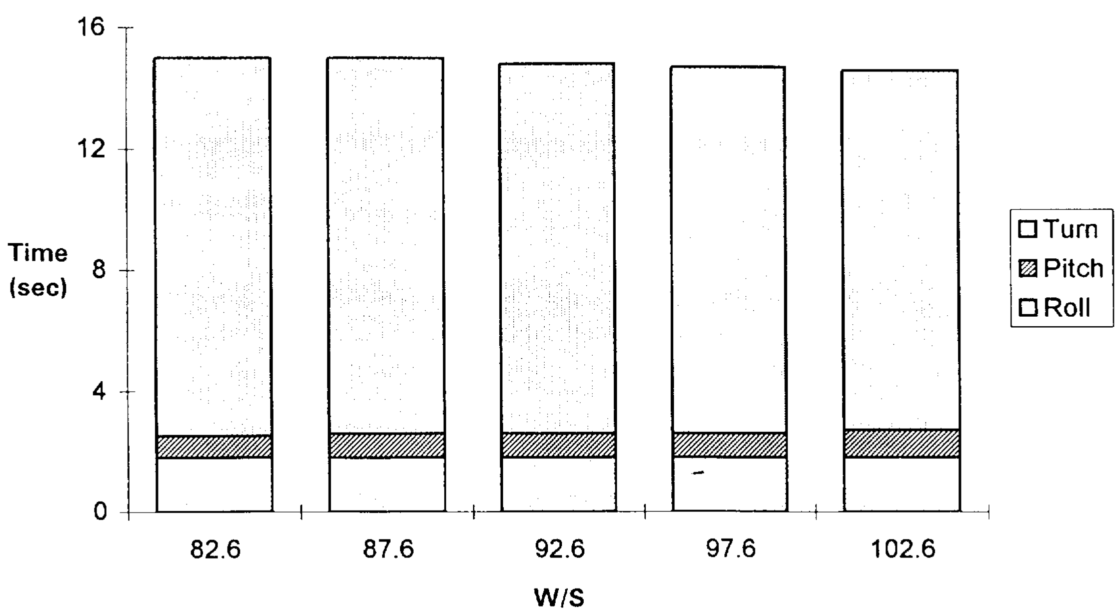


Figure 11 Pointing Margin Total Maneuver Time for Different Wing Loadings

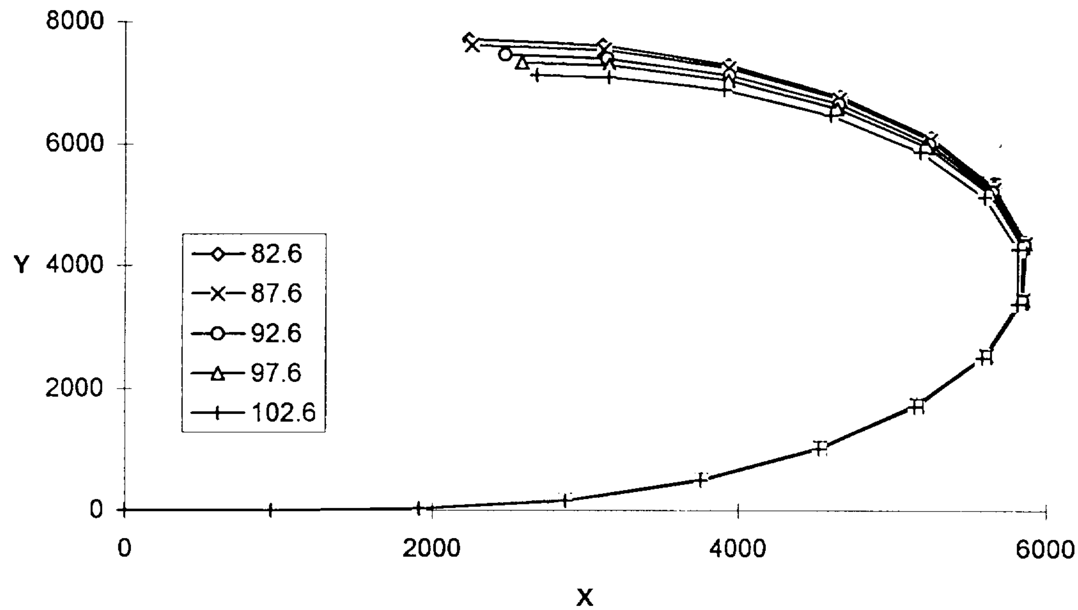


Figure 12 Horizontal Plane Turn Diagrams for Different Wing Loadings

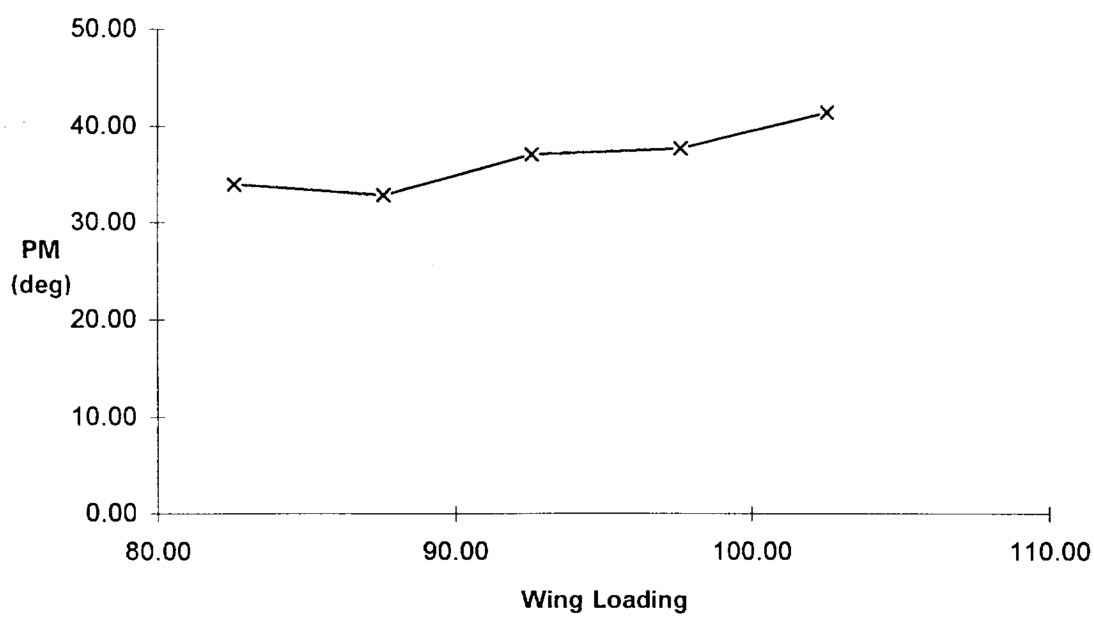


Figure 13 Pointing Margin vs. Wing Loadings

Again, it was illustrated that the results of this study were highly dependent on the particular type of maneuver. If we were looking at some other maneuvers, a higher W/S may not be desired. This shows the difficulty in developing robust agility criteria that provide the best overall performance for a variety of situations and tasks.

5.2 Effect of Thrust Vectoring on Pointing Margin

Vectored thrust offers improved turn performance for future fighters, and is used in the VSTOL fighter to maximize turn-rate. The direction that the thrust should be vectored to depends upon whether instantaneous or sustained turn-rate is to be maximized. In a level turn with vectored thrust, the load factor times the weight must [illegible]

vector for maximum instantaneous turn-rate should be perpendicular to the flight direction while the thrust vector for maximum sustained turn rate should be aligned with the flight direction. Thrust vectoring capability of the agility module does not include pitch control two segments of the maneuvers. A nozzle position angle of zero degrees indicated thrust

along the longitudinal axis of the aircraft. Ninety degrees represented thrust

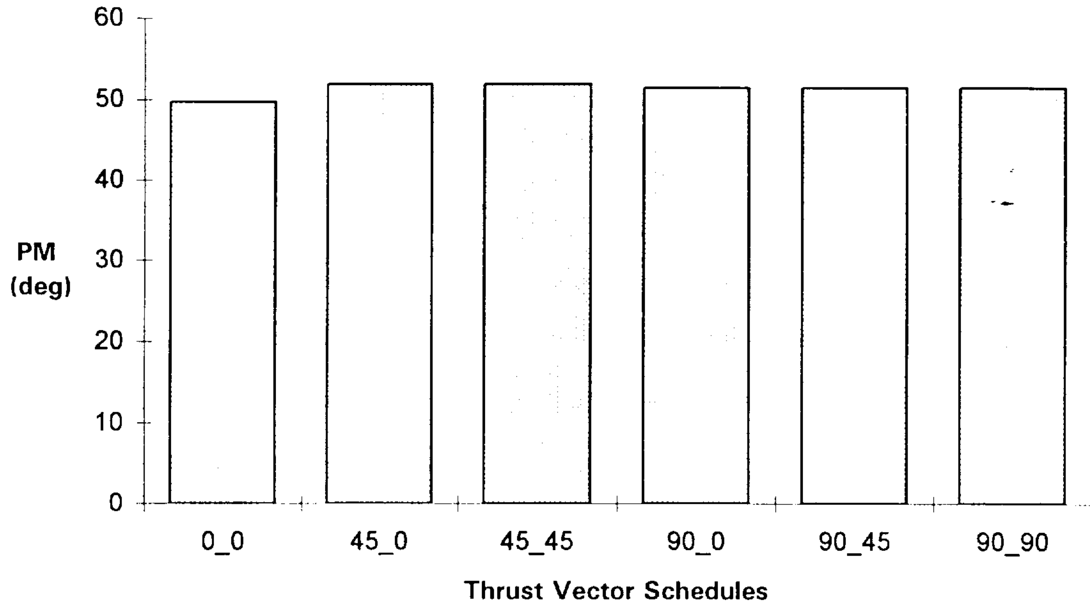


Figure 14 Effect of Thrust Vectoring on Pointing Margin

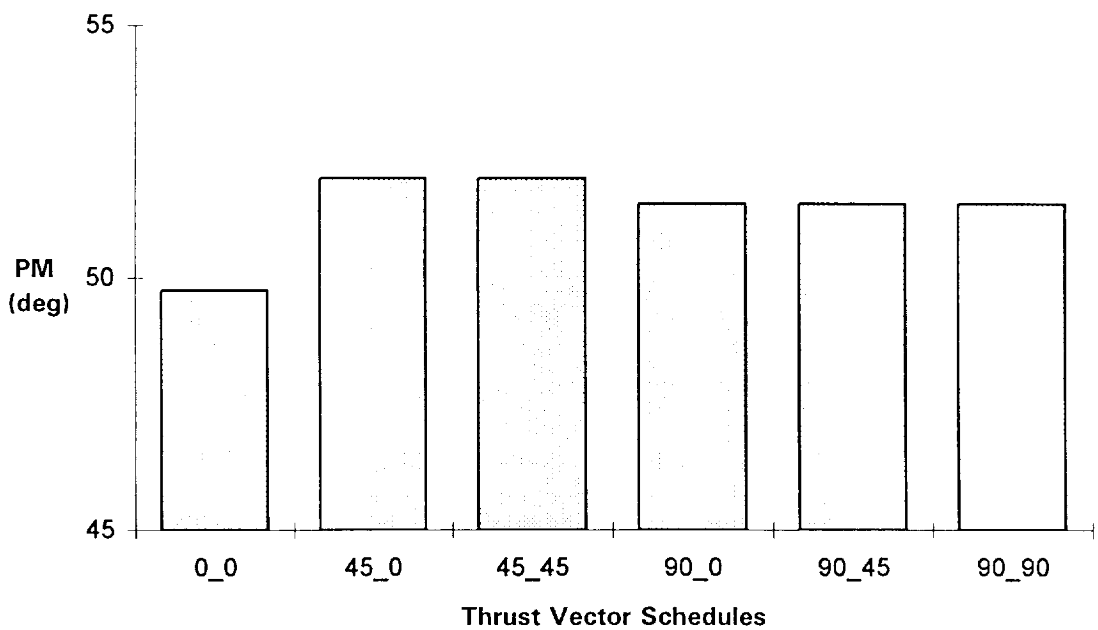


Figure 15 Effect of Thrust Vectoring on Pointing Margin -- Zoom-in View

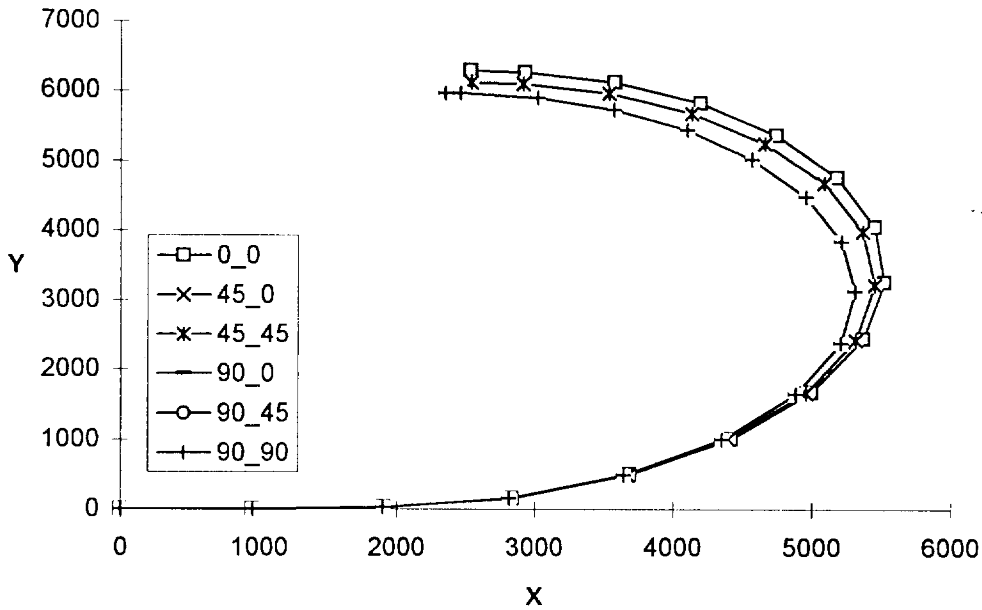


Figure 16 Horizontal Plane Turn Diagrams for Different Thrust Vector Schedules

The overall conclusion is that VT tactics have an apparent advantage in PM analysis and it is good from a positional aspect. Positional advantage (reduced turn radius) is particularly useful in nose-to-nose turns while time advantage (turn rate) is most useful for nose-to-tail engagements.

5.3 Aircraft Optimization with Agility Parameter as One Constraint

Agility module can be used in configuration optimization. This capability is the real power of ACSYNT and it is the optimization studies that will be used to determine the impact of agility technologies and constraints on the overall aircraft configuration.

The basic optimization method used by COPES in conjunction with ACSYNT consists of an objective function, design variables and constraint variables. The objective variable is the parameter being optimized and can be either maximized or minimized. Design variables are the parameters whose values are varied to provide a design space. These design variables are given upper and lower bounds. The constraint variables are parameters that further limit the design space. Typical constraints in ACSYNT are overall aircraft density, a mission range, or a sustained turn requirement at altitude. Only the design variable space that satisfies all constraints can provide possible solutions. The optimizer evaluates aircraft configurations over this design space and attempts to find the design point that produces the best value of the objective variable.

In this case study, the objective variable was gross takeoff weight. For the pointing margin maneuver with an F18 and an F20, the F18 was able to gain a positional advantage and to obtain a pointing margin of 37.15°. The objective for this optimization test run was to minimize the takeoff weight for the F18. Note that only the F18 is being optimized, and not the F20. The constraint for this optimization was to complete the same maneuver with a minimum pointing margin of 37.15°. Figure 17 illustrates the positional plot for the pointing margin maneuver for an F20 and an F18 before and after the optimization. The design variables were the wing area and the engine size. Table 2 lists the design variables bounds, the constraint variable value, and the pertinent parameters of the starting configuration and the optimized configuration. The graphical representation is illustrated in Figure 18.

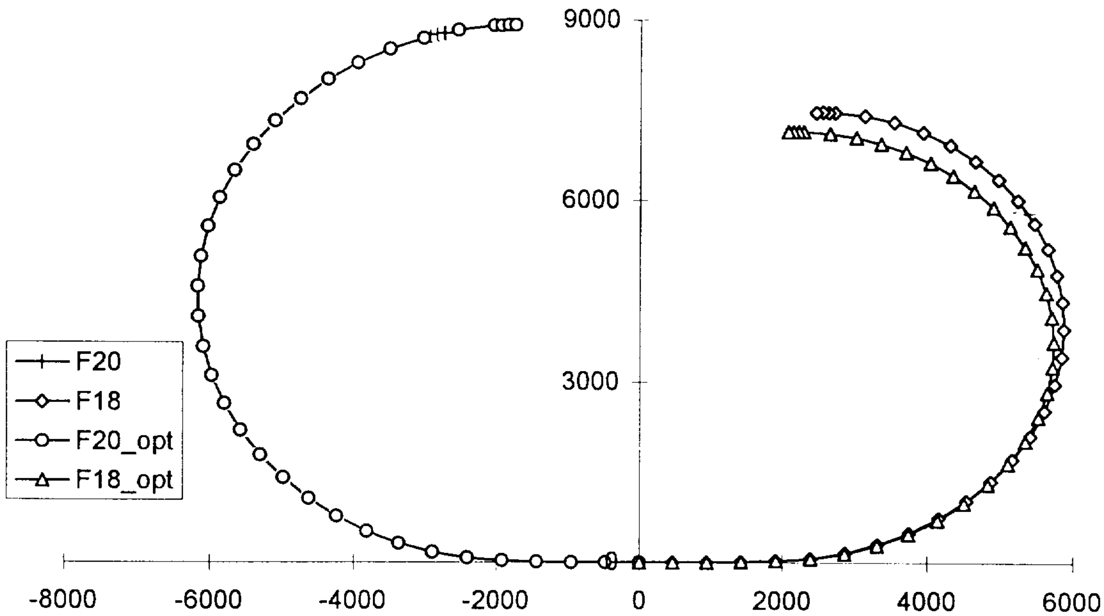


Figure 17 Pointing Margin Maneuvers for F18 and F20 with and without Optimization

Design and Constraint Variable Boundaries

Design Variable	Lower Bound	Upper Bound
Wing Area (ft^2)	150	550
Engine Scale Factor	0.2	1.0
Constraint Variable	Lower Bound	Upper Bound
Pointing Margin (deg)	37.15	40.00

Optimization Results

Configuration	Original	Optimized
Pointing Margin (deg)	37.15	38.92
Wing Area (ft^2)	451.1	350
Engine Scale Factor	1.0	0.937
Takeoff Weight (lbs)	41,783	40,450

Table 2 Design Space Boundaries and Final Results for Pointing Margin Optimization

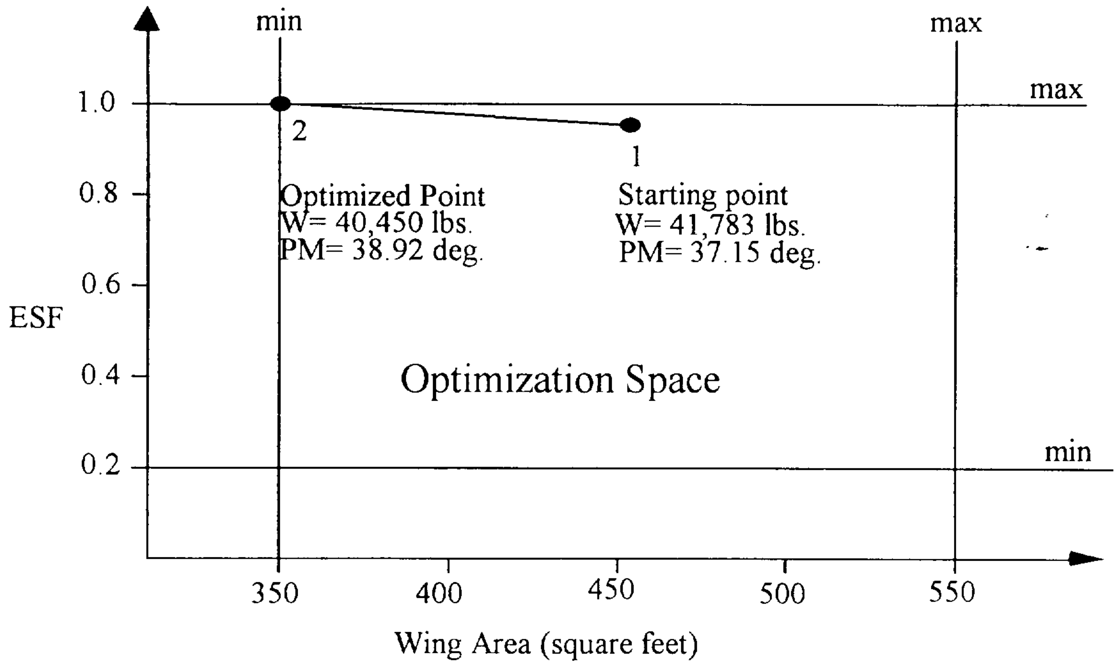


Figure 18 Optimization Path for Minimization of Aircraft Takeoff Weight

The tradeoff is wing loading versus thrust loading. A decrease in wing loading allows a decrease in thrust loading and vice versa. A larger wing and a larger engine both add weight to the vehicle. Some combination of wing and engine size will satisfy the agility constraint and provide the overall lowest takeoff weight. It can be seen on Figure 18 that the trends drive the wing to as small a value as possible. This results in only a moderate increase in engine size. It is shown that the agility criterion is much more sensitive to engine size than wing loading. In real life, any functional aircraft configuration would have many more constraints such as takeoff and landing performance. Those constraints would require a much more reasonable wing size. Nevertheless, this example demonstrates the capability of ACSYNT to use agility constraints in configuration optimization.

6. CONCLUSIONS AND RECOMMENDATIONS

FORTRAN programs were developed and validated for two specific metrics, CCT (Combat Cycle Time) and PM (Pointing Margin), as part of the agility module in ACSYNT design code. This module is an effective design tool in analyzing an aircraft configuration's agility potential. The integrity of the code was proved by comparing with existing flight test data. Example trade studies or the effect of thrust loading, wing loading, and thrust vectoring illustrate how the module can be used to perform trade studies on parameters important to agility metrics that are based on flight test maneuvers. The module is capable of providing constraints for ACSYNT's optimization analysis. Once agility criteria has been developed the module can be used to optimize an aircraft configuration taking into account agility requirements as well as mission requirements.

The present module is best suited for functional type metrics, particularly combat cycle time, pointing margin, and dynamic speed turn. Although the transient metrics may be analyzed and the architecture is well suited for transient maneuvers, the analytical models are not as robust as for the functional type segments. Once ACSYNT is capable of generating stability derivatives and the flight control module is incorporated, the transient maneuver analysis capabilities will be improved.

The validation result has proved that the code is valid for agility analysis.

of agility, an accepted group of metrics, nor quantifiable requirements, the adaptable architecture will allow future metrics and requirements to be incorporated with the least amount of work. The simulation's time-stepping technique of analysis and list of

Pointing Margin are the two dedicated subroutines. Future work effort should involve development of subroutines dedicated to performing other agility metrics. Many of the metrics discussed in the introduction section are appropriate for inclusion in the agility module.

The goal for this agility study is to develop a methodology for inclusion of agility

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